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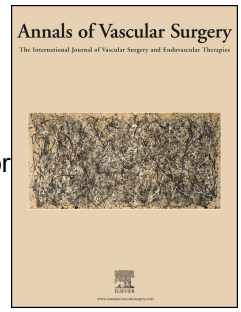

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Low-profile Zenith Alpha™ Thoracic stent graft modification using pre-loaded wires for urgent repair of thoracoabdominal and pararenal abdominal aortic aneurysms

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Abstract

Purpose: To describe a modification technique using the low-profile Cook Zenith Alpha™ thoracic stent graft, and addition of a preloaded wire system, for urgent repair of pararenal (PRA) and thoracoabdominal (TAAA) aortic aneurysms.

Methods: We analyzed 20 consecutive patients who underwent urgent physician modified endograft (PMEG) repair of PRA and TAAA at two institutions. The low-profile Cook Zenith Alpha™ Thoracic stent graft was modified in according with each specific patient anatomic characteristics. Endpoints were technical success, 30-day mortality and major adverse events (MAEs).

Results: Technical success was achieved in all patients (100%). A total of 76 renal-mesenteric arteries were incorporated by fenestrations (70%) or directional branches (30%) with an average of 3.7±0.6 vessels per patient. There were six different types of stent configuration. The most common design consisted of four fenestrations (nine patients, 45%). The average of modification time was 110±27 minutes. Total procedure time (including the time for open component) was 242±75 minutes. There was no death within the first 30-day or hospital stay. MAEs occurred in 10 patients (50%). The most common MAEs were acute kidney injury (by RIFLE criteria) in six patients (30%), EBL >1 L and respiratory failure requiring reintubation in two patients (10%) each, paraplegia and ischemic colitis in one patient (5%) each. One patient (5%) required temporary, new-onset dialysis.

Conclusion: PMEG using low – profile Zenith Alpha™ thoracic stent graft was safe with no early mortality and acceptable early morbidity.

Keywords: Fenestrated Endovascular Aortic Aneurysm Repair; Physician Modified Endografts; Thoracoabdominal Aortic Aneurysm; Low Profile; Preloaded wires.

Introduction

Physician modified endograft (PMEG) technique provides a means for urgent total endovascular repair of pararenal (PRA) or thoracoabdominal aortic aneurysms (TAAAs) in patients who cannot wait for manufactured fenestrated and branched endografts. Previously reported PMEG techniques utilize the Zenith TX2® thoracic stent graft (Cook Medical Inc, Bloomington, Ind) as the base graft.[1-4] Further refinements of the modification technique include addition of diameter reducing wire[5], mini-cuffs[1], directional side branches and pre-loaded wires.[2] Introduced in the U.S. market in 2015, the low-profile Zenith Alpha™ (16~20 French) thoracic stent graft (Cook Medical Inc, Bloomington, Ind) has replaced the Zenith TX2® (20~24 French) as the main workhorse off-the-shelf thoracic stent graft at most centers.[6, 7] We describe our most recent PMEG technique using the low-profile Zenith Alpha™ thoracic stent graft, incorporating the pre-loaded wire system, for urgent repair of PRAs and TAAAs.

Methods

Patient Selection

A retrospective two-center study was undertaken. The study was approved by the Institutional Review Board at each institution. Based on the retrospective nature of the

study, individual patient consent for the study was waived. Both institutions have physician-sponsored investigational device exemption (PS-IDE) studies, but in one institution eight cases were performed outside the PS-IDE study and under compassionate use due to inability to meet the inclusion and exclusion criteria. Off-label nature of the procedure, as well as other treatment options were disclosed to the patients during procedural consent. From March 2016 to January 2019, 20 patients underwent urgent PMEG repair of PRA and TAAAs at two institutions. Patients with high risk for open repair and presented with large, rapidly expanding, or symptomatic aneurysms, in which the requisite time for custom manufactured devices carried a significant risk of rupture were included in the study. PMEG repairs were not performed on patients with ruptured aneurysms presenting with hemodynamic instability. In these patients, induction of general anesthesia or graft modification time carried significant risk of total circulatory collapse.

Device design and planning

Aneurysm morphology was determined by high-resolution computed tomography angiography (CTA) and devices designed with a minimum landing zone of 25mm. Three dimensional multi-planar as well as centerline reconstructions were performed for endograft modification planning. Endograft modifications were designed by surgeons with extensive experience in fenestrated and branched endografting, or dedicated training in complex aortic endografting. Patients with extent I-II TAAAs underwent staged repair with prophylactic spinal drainage. The first stage repair consisted of proximal thoracic stent graft placement, and the second stage fenestrated and branched endovascular repair using the PMEG technique. Neuromonitoring with motor evoked and sensory evoked

potential monitoring was indicated for patients with extent I-II TAAAs at the final procedure. Changes in the neuromonitoring triggers intraoperative maneuvers such as initiation (at 10 mmHg) or increase (down to 0-5 mmHg) of cerebrospinal fluid drainage and permissive hypertension with increments in target mean arterial pressure up to or above 90-100 mmHg. If these maneuvers do not reverse the changes in neuromonitoring, pelvic circulation is restored by retracting the femoral sheaths and allowing circulation to be restored to the hypogastric arteries and lower extremities. If neuromonitoring changes persist at the end of the procedure, temporary aneurysm sac perfusion can be allowed by leaving one of the visceral branches or the contralateral gate of the bifurcated device unstented.

Statistical analysis and definitions

The reporting standards of the Society for Vascular Surgery were used to define stent-graft related outcomes and major adverse events (MAEs).[8, 9] Major adverse events (MAEs) were defined using a composite end point, which included 30-day or in-hospital mortality, acute kidney injury (by RIFLE criteria), new-onset dialysis, myocardial infarction, respiratory failure requiring prolonged mechanical ventilation or reintubation, paraplegia, stroke, bowel ischemia requiring surgical resection or intensive medical care, and estimated blood loss > 1L. Outcome measurements were technical success, 30 – day mortality and MAEs. The results were reported as percent for categorical variables and mean ± standard deviation (median, IQR) for continuous variables.

Technique

To illustrate our technique, we present one case in detail. Patient 3 is a 77-year-old female who presented with a new onset abdominal and flank pain in the setting of a rapidly enlarging 7.5 cm Crawford extent II TAAA. The patient had a type 3 aortic arch, and moderate amount of aortic mural thrombus (**Figure 1**). The first stage operation consisted of a right iliofemoral bypass via a flank incision, and the placement of a tapered Zenith Alpha™ thoracic stent graft (38 ~ 34 x 167 mm). A prophylactic cerebrospinal drain was placed preoperatively.

Modification

A tapered 36 ~ 32 x 209 mm proximal component Cook Zenith Alpha™ thoracic stent graft was modified using strict sterile technique (**Figure 2**). The stent graft was unsheathed and the proximal fixation barbs were removed (**Figure 2A-B**). Fenestrations were created at the predetermined locations using ophthalmic cautery (**Figure 2C**). Each fenestration was reinforced with double layers of Nitinol loops of an endovascular snare EnSNARE (Merit Medical, South Jordan, UT) using locking running 5-0 Ethibond (Ethicon, Cincinnati, OH) sutures (**Figure 2D**). Radiopaque gold markers (Accellent, Washington, Mass) were sutured around each fenestration (**Figure 2E**). The markers were also sutured at 12 and 6 o'clock of the stent graft to note the anterior and posterior position. Diameter reducing ties were added along the posterior wall of the stent graft (**Figure 2F**). All fenestrations were preloaded with 0.014-inch guidewires for the renal arteries or 0.018-inch guidewires for the mesenteric arteries (**Figure 2G**). The modified stent graft was resheathed using 2-0 Silk ties and Silastic tape (**Figure 2H-I, Video**). Side arm branches were created by sewing 1~2cm segment of 6mm (or 8mm self-

expanding Viabahn covered stents (W.L. Gore and Associates, Flagstaff, AZ) onto cauterized orifices, using running 6-0 Gore-Tex sutures (W.L. Gore and Associates, Flagstaff, AZ) (**Figure 3**).

Implantation

Under general anesthesia, left proximal brachial artery was surgically exposed through a 3cm longitudinal incision immediately distal to the axillary hairline. The right iliofemoral bypass graft was re-exposed in the groin. Percutaneous left femoral access was performed with preclose technique using Proglide devices (Abbott Vascular, Santa Clara, CA). The patient was fully heparinized. A 12Fr x 45cm Dryseal Flex® sheath (Gore and Associates, Flagstaff, AZ) was introduced from the left brachial approach and positioned in the descending thoracic aorta. Through-and-through brachiofemoral access was established, then a 5Fr x 90cm sheath was placed over this access. The preloaded wires were passed through the 5-Fr through-and-through sheath (**Figure 4A**). The modified Zenith Alpha™ stent graft was introduced over the Lunderquist wire, and advanced to the paravisceral aorta with the 5-Fr sheath. The 5Fr sheath was removed from the brachial access. Under the guidance of Fusion CT (GE Discovery IGS 730, GE Healthcare, Chicago, IL), the stent graft was positioned with each fenestration in alignment with its target vessel (**Figure 4B**). The stent graft was partially deployed while individual visceral and renal branches were sequentially catheterized from the brachial approach, using the preloaded wires (**Figure 4C**). The branch catheterization technique using preloaded wires was previously described.[2] For the celiac axis (CA), 0.018-inch Steelcore wire was used, while 0.035-inch Amplatz and 0.035-inch Rosen wires were

used for the superior mesenteric artery (SMA), and renals. Following the complete target branch catheterization, the stent graft was fully deployed, and diameter-reducing wire removed. The renal arteries were stented with 5mm x 22mm iCAST covered stents (Atrium, Merrimack, NH) (**Figure 4D-E**). The CA and SMA were stented with 7mm x 22mm and 7mm x 38mm iCAST, respectively (**Figure 4F-G**). All branch stents were flared to 10mm across the fenestrations. The repair was extended distally using 36mm Zenith aortic cuff (Cook Medical, Bloomington, IN). The completion angiography showed complete aneurysm exclusion with widely patent branch stents (**Figure 4H**).

Results

Patient characteristics

Mean age of our cohort was 74±8 years (73, 68 –78), and 10 patients (50%) were male (**Table I**). Aneurysms were classified as TAAA in 16 patients (80%; Extent I in 1, II in 6, III in 5, and IV in 4) or PRA in 4 patients (20%). Mean aneurysm diameter was 74±17 mm (70, 63 – 88). The most prevalent cardiovascular risk factors were hypertension in 19 (95%) and prior history of cigarette smoking in 18 patients (90%). Ten patients (50%) presented with symptomatic non-ruptured or contained rupture of the aortic aneurysm.

Stent-graft design

There were six different types of stent configuration. The most common design, which was selected in 9 patients (45%), consisted of four fenestrations for the CA, SMA and renal arteries. Four patients had a single functioning kidney with chronic occlusion of one renal artery resulting in the incorporation of only three target vessels. A total of 74 renal-mesenteric arteries were incorporated by fenestrations (70%) or directional

branches (30%) with an average of 3.7±0.6 (4, 3 – 4) vessels per patient (**Table II**). All fenestrations and directional branches were loaded with 0.018 or 0.014-inch wires. The average modification time and length of the main device modified were 110±27 (105, 96-131) minutes and 179±29 (170, 161-207) millimeters, respectively.

Procedure detail

Technical success, defined by deployment of the aortic stent-graft and all intended side branch components, was achieved in 100% of patients (**Table II**). Twelve patients (60%) had prophylactic placement of cerebrospinal fluid drainage. Among eight patients that did not receive prophylactic spinal drain, aneurysm type was extent IV in four patients, pararenal in three and extent II in one. Mean endovascular procedure time was 166±85 minutes (118, 98 – 262) with fluoroscopy time of 74±27 minutes (72, 59 – 89), and 131±52 ml of iodinated contrast (120, 90 – 150) was used for each case. Total procedure time (including the time for open components) was 242±75 minutes (215, 192 – 281). Nine patients (45%) had the procedure in staged fashion with average of 17±29 (5, 2-21) days for the second stage, completion procedure.

Early outcomes

There was no death within the first 30-day or hospital stay. The mean length of hospital stay was 9±7 days (7, 5 – 11). Ten patients (50%) had major adverse events (MAEs, **Table III**). The most common MAEs were acute kidney injury (by RIFLE criteria) in six patients (30%), EBL >1 L and respiratory failure requiring reintubation in two patients (10%) each, paraplegia and ischemic colitis in one patient (5%) each. One patient (5%) required temporary, new-onset dialysis. Two patients (10%) had a minor perioperative stroke (NIH Stroke Score 2). The patient with paraplegia, had four

directional branches endovascular repair of the symptomatic non-ruptured Extent II TAAA. He woke up neurologically intact from anesthesia. CSF drainage was open, and mean arterial pressure (MAP) was maintained > 80mmHg. Eight hours later, patient had an acute onset sharp back pain radiating to legs and became densely paraplegic. This never improved despite adjunctive measures.

Four patients required early secondary intervention to treat one type IA endoleak and three access complications. Follow-up imaging was obtained in all patients. After mean follow-up of 5±6 (3, 1-9) months, there was no reintervention, aortic-related death or branch instability.

Discussion

Collective experience with fenestrated, branched stent graft technology is well established with implantation in thousands of patients, and continues to grow at a rapid pace. Concurrently, advances in low profile aortic stent graft technology have been incorporated to the manufactured fenestrated and branched devices. However, customized endografts take weeks for delivery and off-the-shelf devices for complex aortic anatomy are limited. Hence, the role of PMEGs continues to exist in urgent cases without viable open surgical options.

Reported outcomes by the authors regarding PMEGs have been favorable. Oderich and colleagues reported their series of 30 patients, 47% of which had TAAA. For a total of 85 fenestrations, branch stenting success was 98%, with one perioperative death. In this study, median follow-up was 14 months, with 1-year branch patency of 97% and freedom from endoleak of 88%.[10] In 2012, Starnes and colleagues described

their initial outcomes of 47 consecutive patients with juxtarenal aneurysms treated with PMEG.[11] Technical success was 98%, with a total of 82 fenestrations, and a perioperative mortality of 2%. Since then, Starnes and colleagues have published their updated mid-term results now with 64 consecutive patients, 145 total fenestrations, and 4-year follow-up.[12] Technical success remained high at 95% and 30-day mortality of 5.1%. Complication rate was 12% including three myocardial infarctions, one stroke, one renal failure, and four respiratory failure. Freedom from stent-graft migration and freedom from rupture or conversion to open at 12 months was 100%. Only two patients had type I or type III endoleak at 12 months. No new endoleaks have been detected in patients seen at 4-year follow-up. Sac stability or shrinkage was seen in 97.7% of patients at one year and 95.2% of patients at three years. Mean follow up was 28 months, with four aneurysm-related deaths. All four aneurysm-related deaths were within the 30-day perioperative window, while an additional eight all-cause mortalities occurred during follow-up for an overall survival of 70% at 4 years.

Recent report from a high-volume aortic center in Hamburg, Germany demonstrated similarly high technical success of PMEG even in the setting of contained rupture.[13] Their cohort of 21 patients consisted of 11 TAAA, and 13 patients presenting with contained rupture. Technical success of PMEG implantation was achieved in 100% of the patients. Thirty-day survival was 95%. Two cases of permanent paralysis were in patients who had intraoperative hypotension due to rupture. There was 1 late aneurysm-related death in a patient who developed an aortoenteric fistula. At 11 months follow up, all branch stents remained patent. This report highlights that PMEG technique remains useful even in European centers where the off-the-shelf device (t-Branch) is available on

the market. The authors noted that "since customized endografts take weeks for delivery and off-the-shelf devices for complex aortic anatomy are limited, the surgeon-modified stent-grafts appears to be an effective endovascular option because it facilitates an anatomically correct reconstruction."

O'Donnell and colleagues analyzed the outcomes of 1396 complex EVARs using the national Vascular Quality Initiatives database. Complex EVARs consisted of 880 FEVARs using commercially available ZFEN (Cook Medical, Bloomington, IN), 256 PMEGs, and 260 chimney/snorkel EVARS. Compared to ZFEN and chimney/snorkel EVARs, PMEGs were utilized to treat more extensive aneurysms, incorporating more branch vessels (mean: 3.3±0.8 arteries vs. 2.5±0.6 ZFEN, and 1.9±0.9 chimney/snorkels) involving more celiac and SMA. However, PMEG had the lowest unadjusted perioperative death rate (2.7%), compared to ZFEN (3.4%) and chimney/snorkel (6.1%). Stroke rates after PMEG (0.9%) and ZFEN (0.8%) were similar, while chimney/snorkel EVARs had significantly higher stroke rates (3.3%, p=.03). This study reflects that 1) PMEGs play a significant role in the real-world practice of complex EVARs in the United States, and 2) short-term results achieved by PMEG are similar to the excellent results achieved by ZFEN, and superior to snorkel/chimney EVARs.[14]

Since the published PMEG techniques using TX2 platform (Cook Medical, Bloomington, IN)[1-4], the low-profile Zenith Alpha™ thoracic stent grafts have largely replaced the TX2 as the off-the-shelf thoracic stent graft at many centers. True urgent and emergent cases will most commonly involve use of readily available stent grafts. As such, familiarity with the low-profile Zenith Alpha™ thoracic stent graft and its

modification steps are critical components of achieving successful outcomes using PMEG technique.

There are several differences in the PMEG technique using the Zenith Alpha™ thoracic stent graft, from its predecessor, TX2. First, widely spaced Nitinol stents on the Alpha device (**Figure 5**), compared to much tighter stainless-steel Z stents offer more space to place the fenestrations without having to bend and relocate the stent wires (**Figure 6**). Second, our approach to creating fenestrations involves efforts to reproduce the features of manufactured devices. Every fenestration is created to be 8x8mm or smaller and reinforced with a double layer of EnSNARE (Merit Medical, South Jordan, UT) wires constructed of braided Nitinol. The wires are secured around the fenestration by tightly spaced 5-0 Ethibond locking sutures (**Figure 2B**). These steps are aimed at maximizing durable seal across the fenestrations with flared balloon expandable covered stents. Sterile gold markers are placed in the configuration of the manufactured devices. Third, it is our preference to remove the active fixation barbs in order to facilitate intracorporeally rotation of the device.

Despite of the high-risk patients (100% of patients were American Society of Anesthesiology category III or IV) in the urgent or emergent setting, our results compare favorably with the pre-existing literature.[12-16] Technical success was achieved in 100% of patient with no 30-day mortality. Preloaded wire technique on the Zenith Alpha platform facilitates successful target vessel catheterization, as evidenced by mean fluoroscopy time of 74min, contrast amount of 131ml. This compares favorably to the largest PMEG experience previously published (fluoroscopy time: 108mins, and contrast:

191ml).[15] The rates of MAEs were acceptable with low secondary intervention. Branch patency was 100% after mean follow-up 5±6 months with no branch instability observed.

Despite these promising early results, some points of caution should be noted. Because there is no quality control and there is no oversight from industry representatives or a planning center, the technique is entirely dependent on the operator's experience with sizing, modifications, and device implantation. Modifications that are ill planned or poorly conducted can lead to disastrous complications and are often not reported in the literature. In addition, physician modifications of an approved device automatically exempt the manufacturer from any product liability claim. Although any physician can perform these modifications, the Food and Drug Administration (FDA) and the SVS do not endorse the technique unless it is performed under an investigational study. Last, PMEGs are costly and may not be fully reimbursed if they are performed outside these investigational studies.[17]

In conclusion, physician modified endograft technique can be applied to the low-profile Zenith Alpha™ thoracic stent graft, to enable urgent total endovascular repair of thoracoabdominal and complex aortic aneurysms in patients with high risk for open repair who cannot wait for manufactured devices.

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402 **Table I.** Demographics, clinical and anatomical characteristics of 20 patients treated
403 using physician modified endograft (PMEG with Zenith Alpha™ thoracic stent graft.

n= number of patients	**Overall**
	n=20 (%) or mean ±SD (median, IQR)
Demographics	
Age (years old)	74±8 (73, 68-78)
Age > 80 years old	4 (20)
Male gender	10 (50)
Cardiovascular risk factors	
Cigarette smoking	18 (90)
Hypertension	19 (95)
Hypercholesterolemia	17 (85)
Coronary Artery Disease	11 (55)
COPD	10 (50)
Peripheral arterial disease	5 (25)
CKD Stage	
Stage I	2 (10)
Stage II	8 (40)
Stage III	8 (40)
Stage IV	2 (10)
CKD Stage III-IV	11 (55)
Diabetes Mellitus	1 (5)
Congestive Heart Failure	3 (15)
Stroke/TIA	3 (15)
Prior aortic repair	12 (60)
Ascending or arch	2 (10)
Open-Infrarenal	4 (20)
EVAR-AAA	1 (5)
TEVAR-1 Stg	9 (45)
Preoperative evaluation	
Serum Creatinine (mg/dl)	1.2±0.5 (1.0, 0.9-1.3)
eGFR (mL/min/1.73 m^2)	61±22 (59, 49-81)
Body Mass Index (kg/m^2)	27±7 (25, 22-30)
Risk assessment	
ASA Score	
Class 3	10 (50)
Class 4	10 (50)
Anatomical Characteristics	
Max aortic diameter	74±17 (70, 63-88)

Aneurysm Type	
Crawford extent I	1 (5)
Crawford extent II	6 (30)
Crawford extent III	5 (25)
Crawford extent IV	4 (20)
Pararenal	4 (20)
Post-dissection TAAA	1 (5)

Table II. Procedure detail and device design of 20 patients treated using physician modified endograft (PMEG) with Zenith Alpha™ thoracic stent graft.

	Overall
	n=20 (%) or mean ±SD (median, IQR)
n= number patients	
General Anesthesia	20 (100)
Status of aneurysm	
Large/rapidly expanding aortic aneurysm	10 (50)
Symptomatic non-ruptured	9 (45)
Contained ruptured	1 (5)
Cerebrospinal Fluid Drainage	12 (60)
Somatosensory evoked potential/Motor evoked potentials	14 (70)
Preloaded wires	20 (100)
Reducing diameter tie	20 (100)
Brachial access	19 (95)
Left side	17 (85)
Right side	2 (10)
Percutaneous femoral approach	15 (75)
Unilateral	11 (55)
Bilateral	8 (40)
Iliac conduit	1 (5)
Modification time (min)	110±27 (105, 96-131)
Length of the main device modified (mm)	179±29 (170, 161-207)
Amount of contrast used (ml)	131±52 (120, 90-150)
Total endovascular time (min)	260±44 (271, 232-292)
Total fluoroscopy time (min)	74±27 (72, 59-89)
Total air kerma (mGy)	1975±1595 (1678, 707-3156)
Dose Area Product ($Gy.cm^2$)	233±154 (158, 134-291)
Estimated blood loss (ml)	423±283 (350, 250-600)

Hospital stay (days)	9±7 (7, 5-11)
Technical success	20 (100)
Device design	**74**
Target vessel per patient	3.7±0.6 (4, 3-4)
Fenestration	52 (70)
Directional branches	22 (30)
Celiac axis	17 (23)
Fenestration	13 (18)
Directional branches	4 (5)
Superior mesenteric artery	20 (27)
Fenestration	14 (19)
Directional branches	6 (8)
Right renal artery	19 (26)
Fenestration	13 (18)
Directional branches	6 (8)
Left renal artery	17 (23)
Fenestration	11 (15)
Directional branches	6 (8)
Additional artery (Accessory RRA incorporated by fenestration)	1 (1)

Table III. Mortality and major adverse events (MAEs) < 30 days of 20 patients treated using physician modified endograft (PMEG) with Zenith Alpha™ thoracic stent graft.

	Overall
	n=20 (percent)
n= number patients	
Early death	0 (0)
Any major adverse event	10 (50)
Estimate blood loss higher than 1000 ml	2 (10)
Acute Kidney Injury by RIFLE criteria	6 (30)
New-Onset Dialysis	1 (5)
Myocardial Infarction	0 (0)
Respiratory failure	2 (10)
Any spinal cord injury	2 (10)
Grading Classification	
1-2 (paraparesis)	1 (5)
3a-c (paraplegia)	1 (5)
Timing	
Immediate	0 (0)
Delayed	2 (10)
Any stroke	2 (10)
Stroke major	0 (0)
Stroke minor/TIA	2 (10)
Bowel ischemia	1 (5)
Access complication	3 (15)

RIFLE, Risk, Injury, and Failure; and Loss; and End-stage kidney disease.

Figure 1. Computed tomography angiography demonstrated a 7.7cm extent II thoracoabdominal aortic aneurysm (**A**). The descending thoracic aorta had a moderate amount of mural thrombus (**B**). The celiac artery (**C**) and superior mesenteric artery (**D**) were patent. Increased amount of shaggy aortic mural thrombus was noted at the level of the right renal artery with moderate stenosis (**E**). The left renal artery had a high-grade stenosis with calcified ostial lesion (**F**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved.

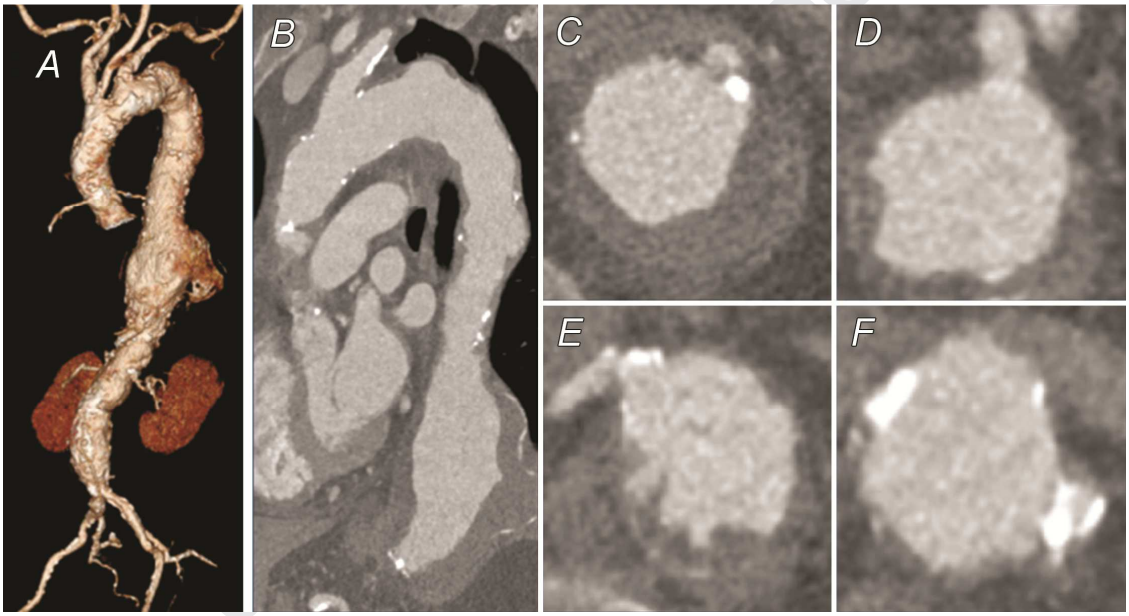
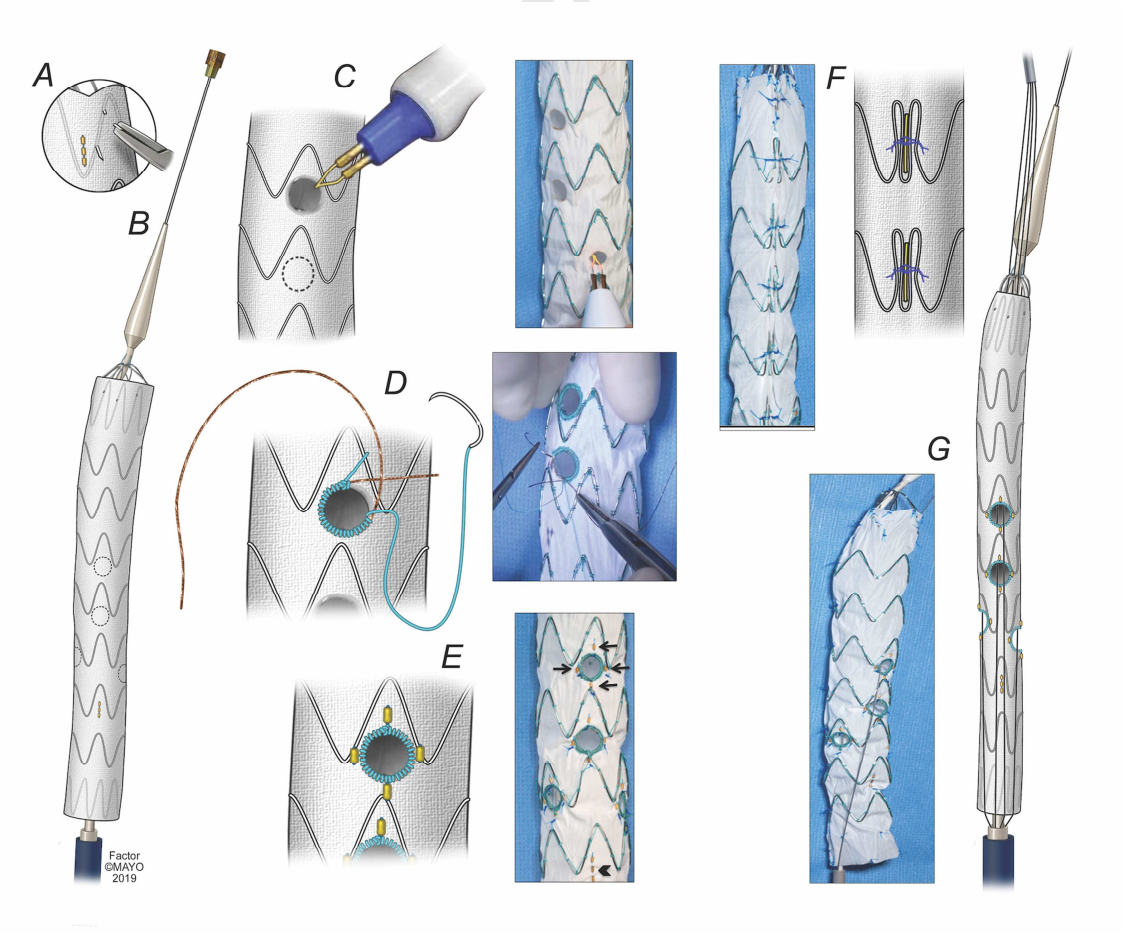


Figure 2. A tapered low profile alpha proximal component thoracic stent graft was unsheathed. The device was modified on site by creating fenestrations for the visceral and renal arteries (**A-C**). Fenestrations were reinforced with double layers of braided nitinol wires using running 5-0 Ethibond sutures (Ethicon, Cincinnati, OH) (**D**). Each fenestration was marked with four gold radiopaque markers (arrows). Longitudinal anterior markers (arrow head) and transverse posterior markers were added (**E**). Diameter reducing ties were added along the posterior aspect of the endograft (**F**). Each fenestration was preloaded with a 0.014 wire (**G**). The device was constrained with Silk ties and silastic tape, then reloaded into the sheath retrograde (**H-I**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved.



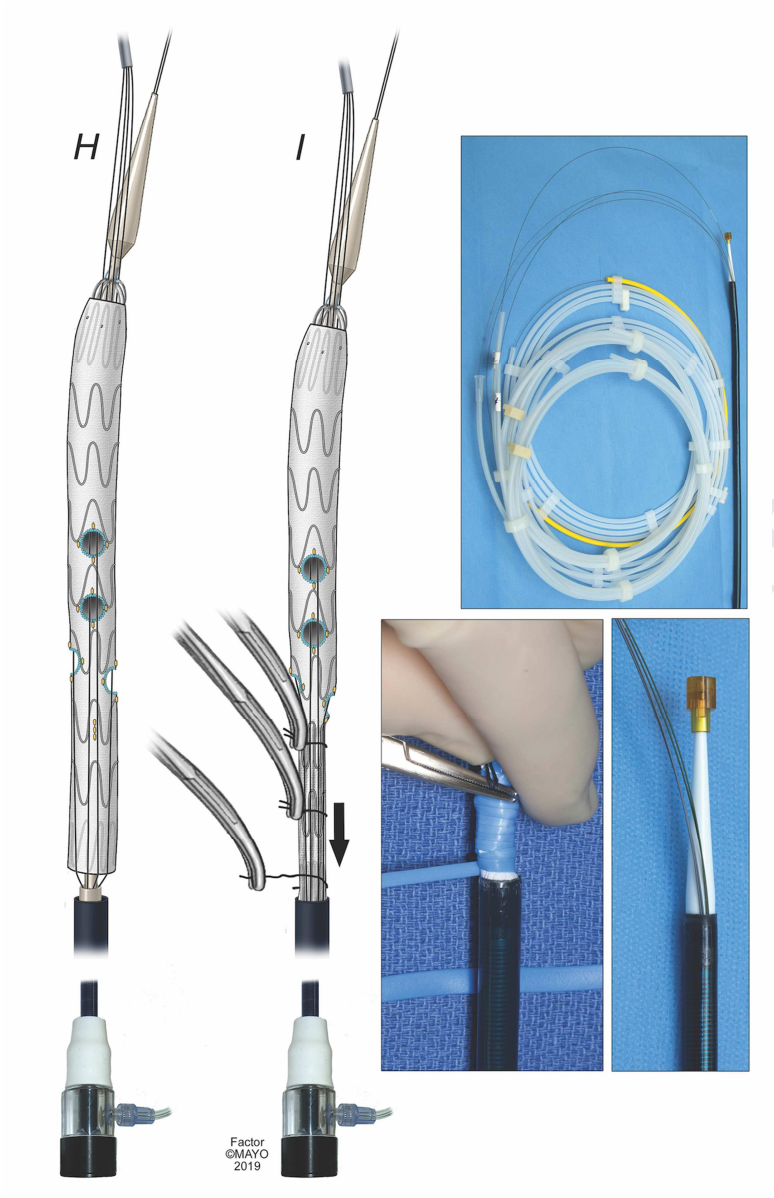


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Figure 3. Directional branches are fashioned using 2-cm long Viabahn stent grafts (WL Gore, Flagstaff, AZ). The distal edge of the branch is positioned approximately 2 cm above the intended location of the target vessel within the same clock position. A Viabahn stent graft (**A**) is anastomosed end to side to the fenestration using running 5–0 Gore sutures (WL Gore, Flagstaff, AZ). The distal edge of the Viabahn branch is stitched to the fabric of the TX2 stent graft to prevent movement during re-sheathing and deployment. Radiopaque markers are placed at the proximal and distal edge of the fenestration and at the distal edge of the branch (**B**, *black arrows*). By permission of Mayo Foundation for Medical Education and Research. All rights reserved.

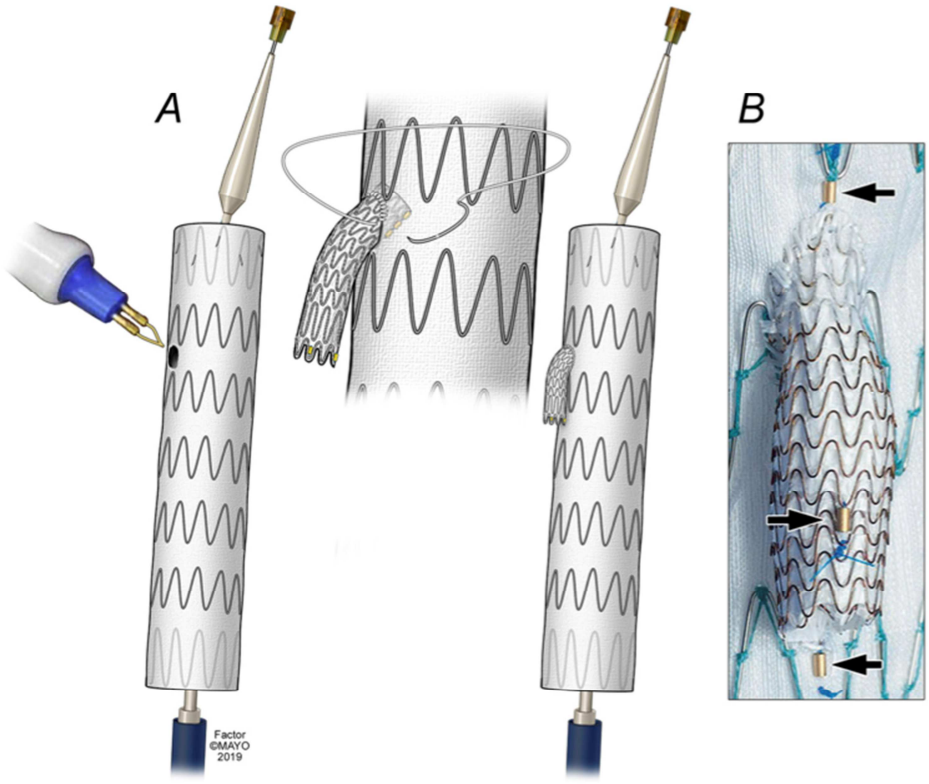
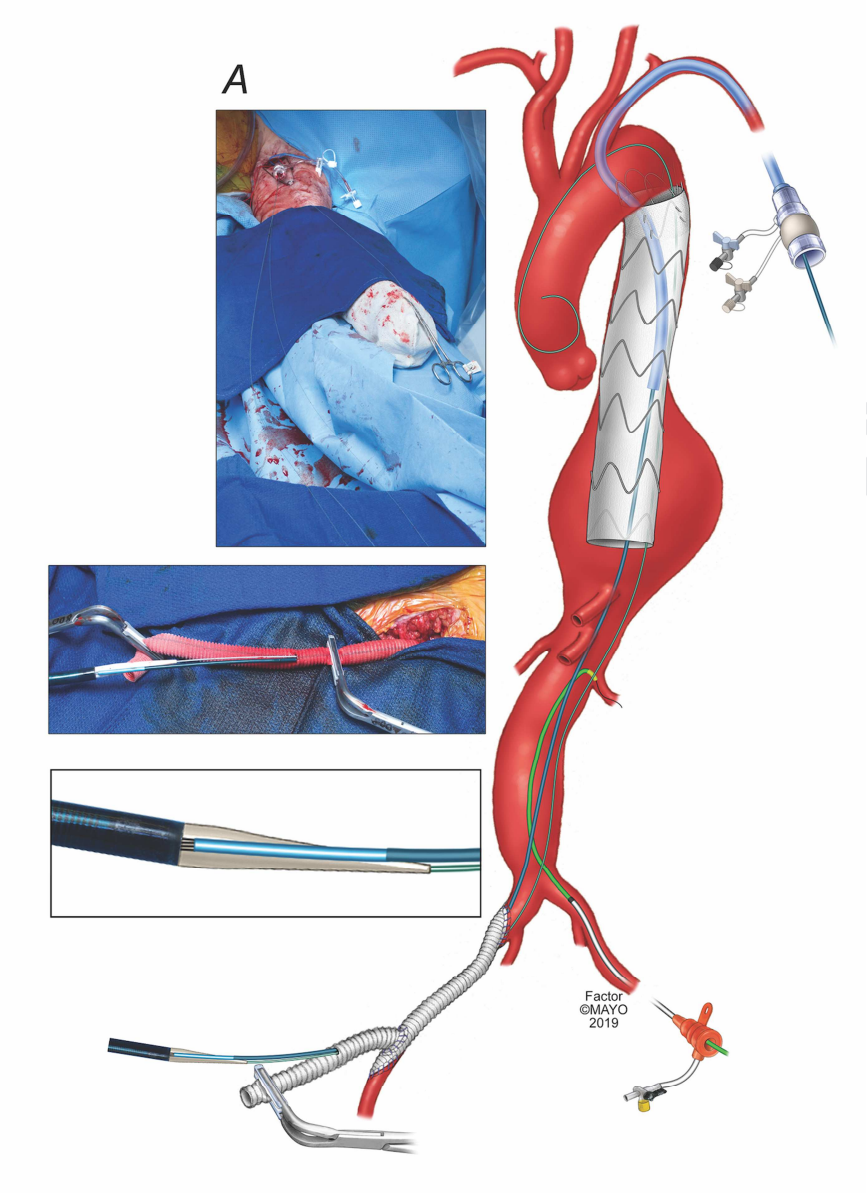


Figure 4. Through-and-through brachiofemoral access was established, then a 5Fr x 90cm sheath was placed over this access. The preloaded wires were passed through the 5-Fr through-and-through sheath (**A**). The modified stent graft was advanced along with the 5Fr brachiofemoral sheath. The stent graft was positioned under fusion imaging guidance, and was deployed in staggered fashion (**B**), allowing sequential branch catheterization using the preloaded wires (**C**). Following placement of branch bridging stents (**D-G**), and completion angiography showed patent branch stents and no endoleak (**H**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved.



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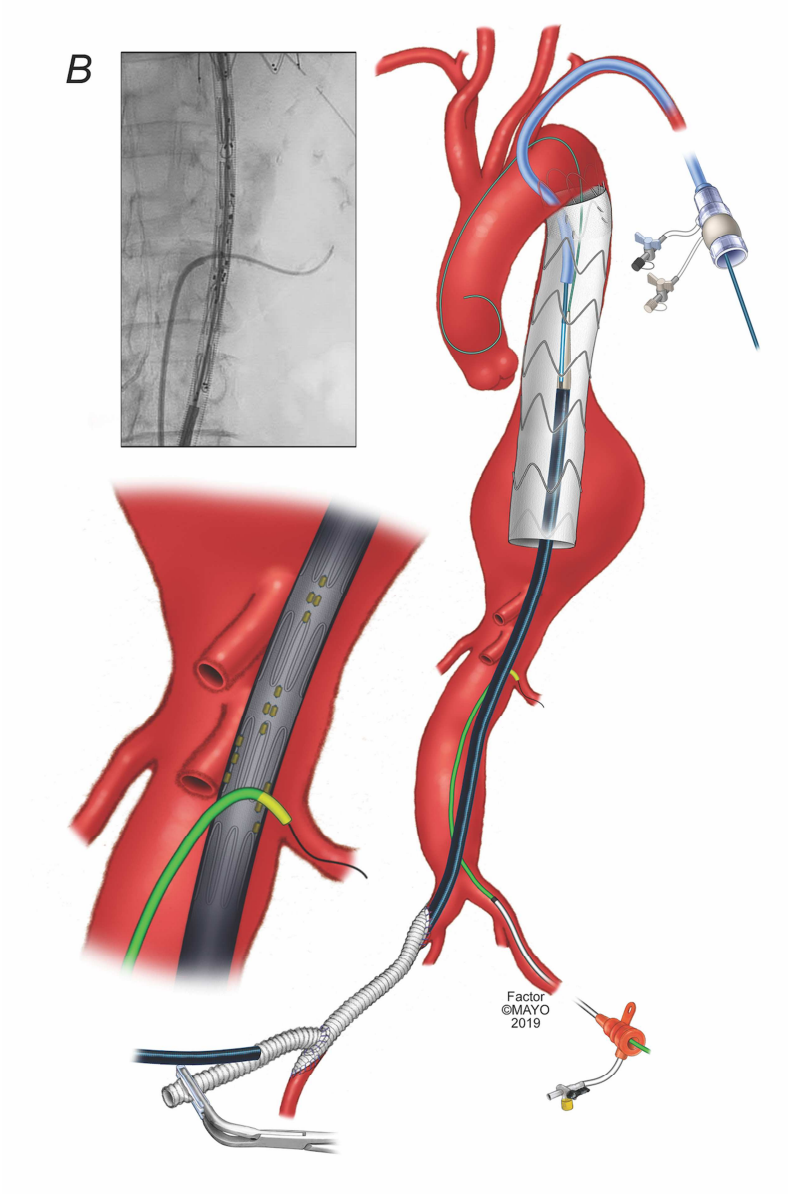

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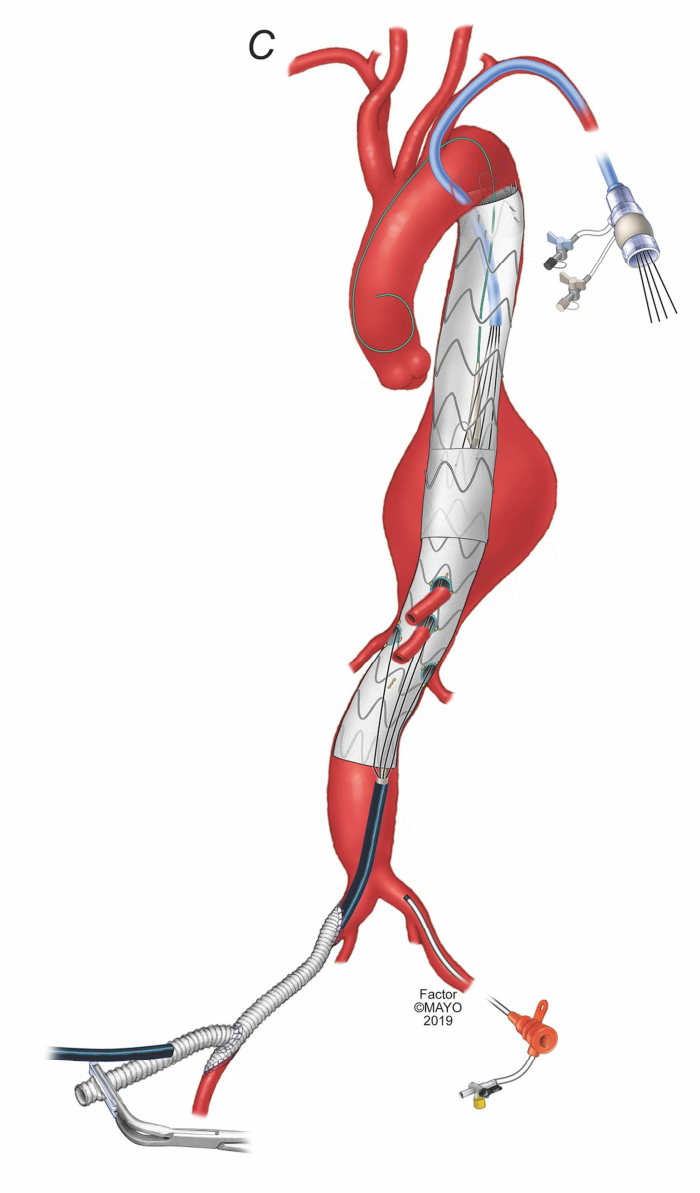

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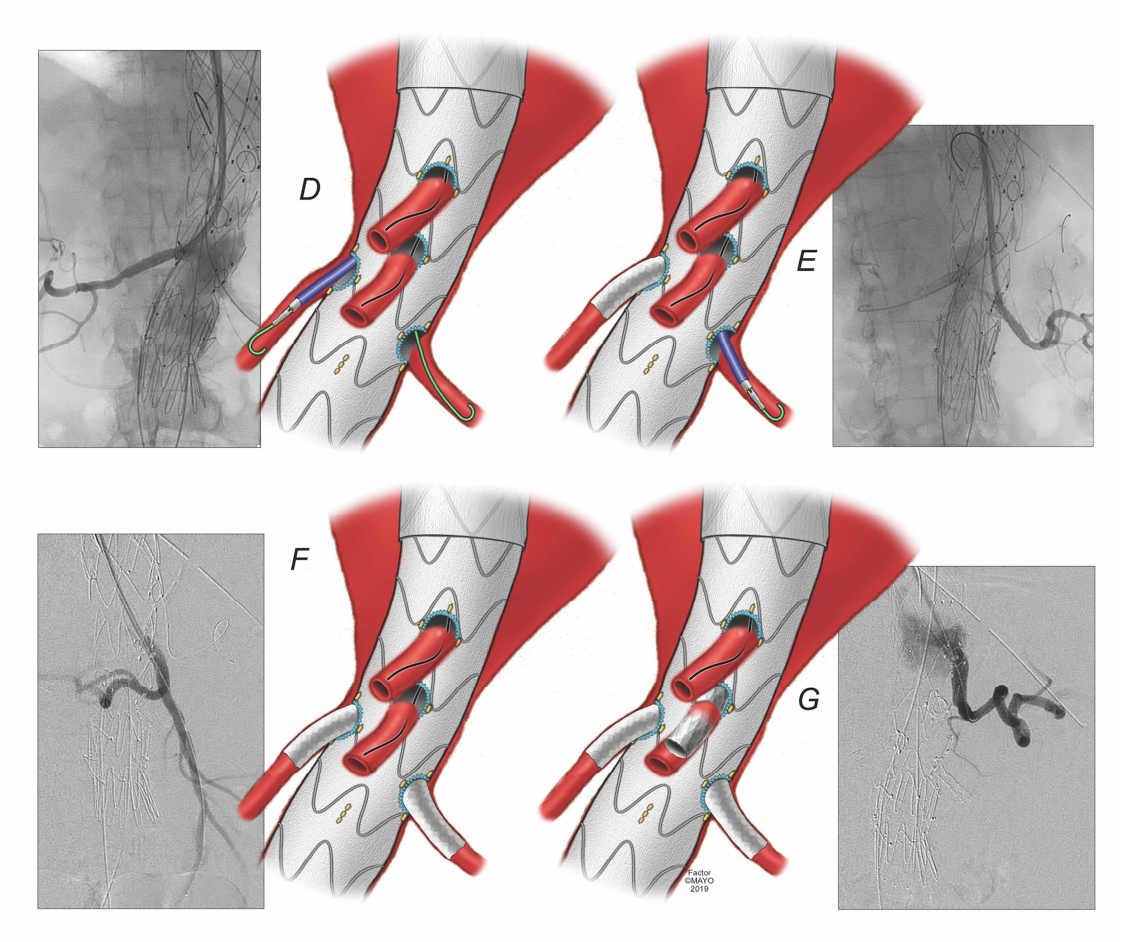

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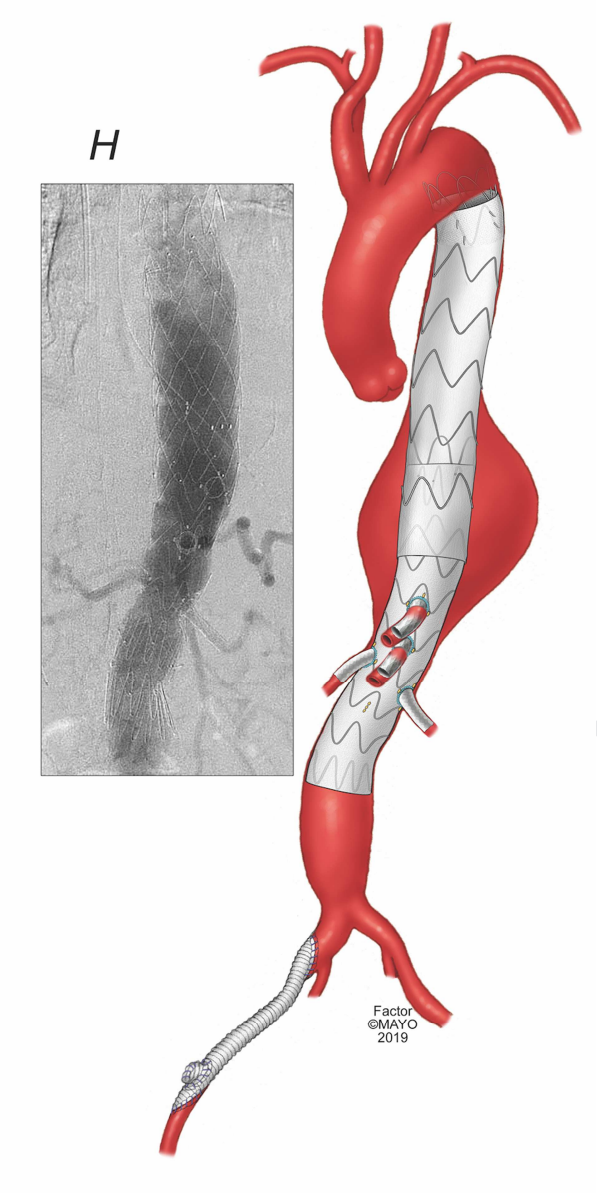

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Figure 5. Distance apex to apex range (a) from 9.4mm ~ 11mm for Zenith TX2® thoracic stent graft (**A**), and 18.1mm ~ 18.8mm for Zenith Alpha™ thoracic stent graft (**B**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved.

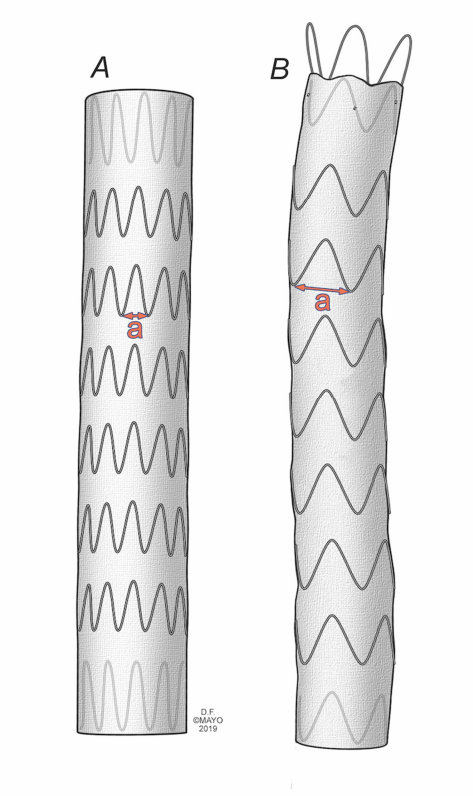
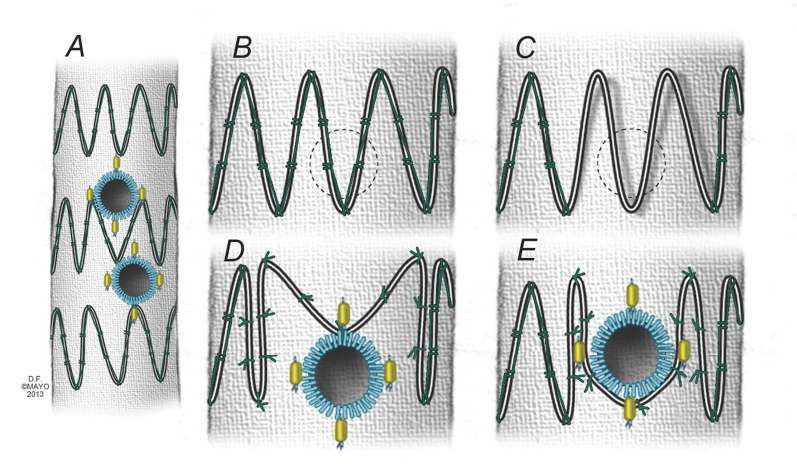
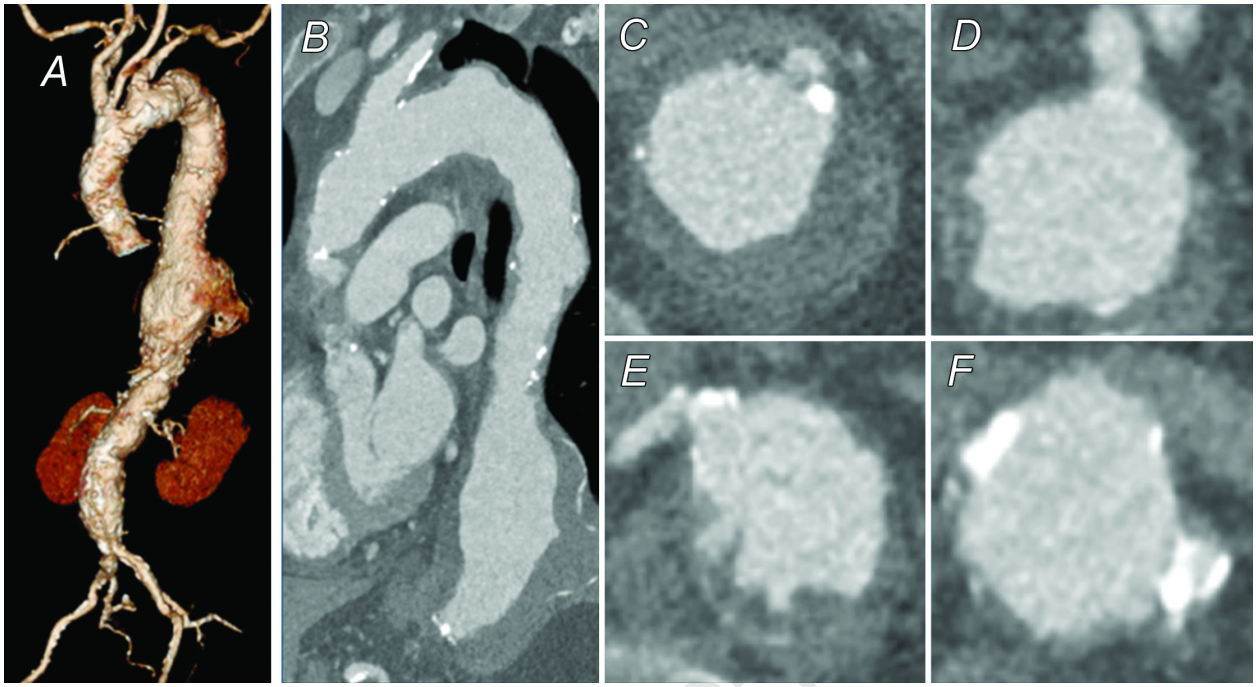
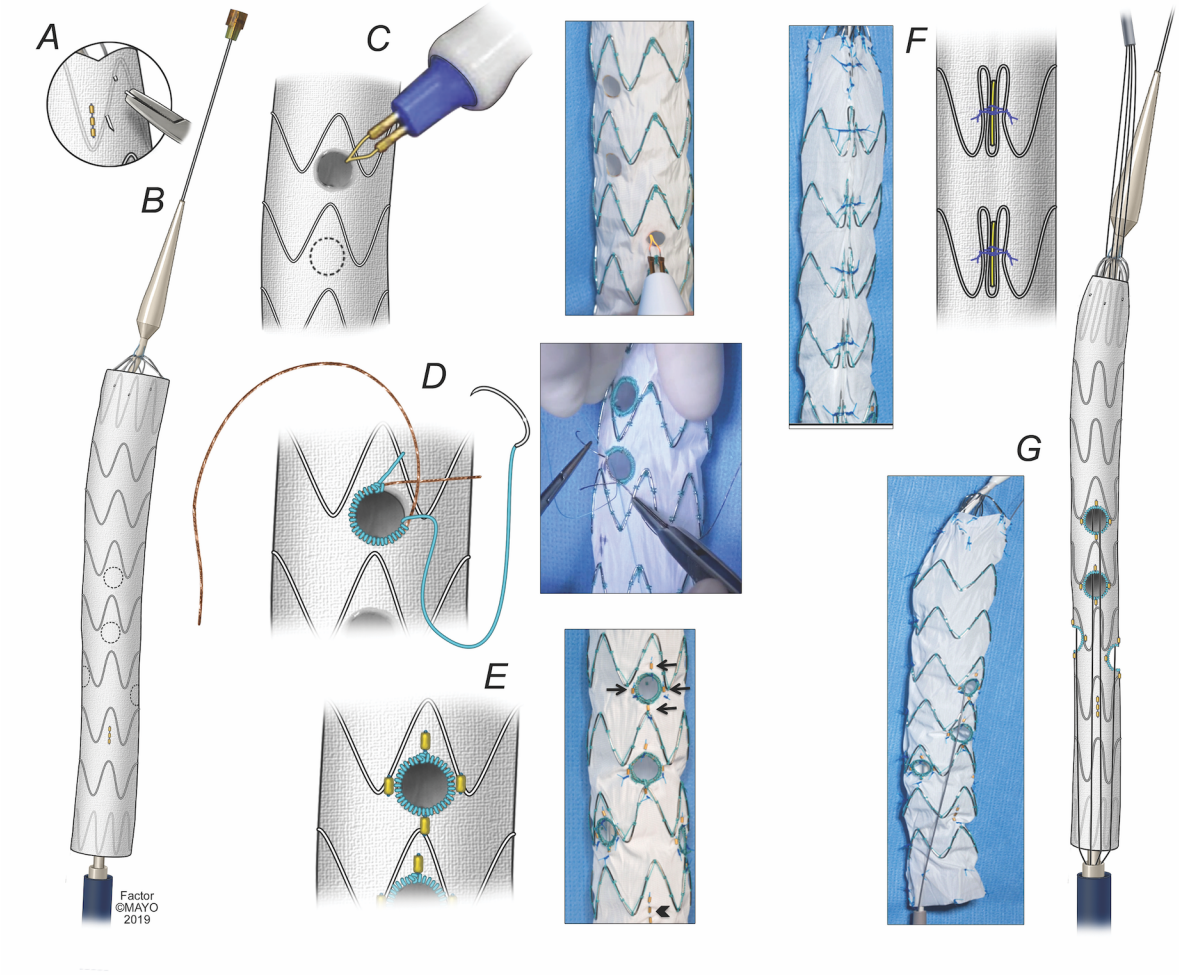


Figure 6. Stent relocation technique to accommodate fenestrations in Zenith TX2® thoracic stent graft requires bending and resuturing the Z stents (**D-E**). By permission of Mayo Foundation for Medical Education and Research. All rights reserved.



Video. Physician modified endograft (PMEG) technique using the low-profile Zenith Alpha™ thoracic stent graft. By permission of Mayo Foundation for Medical Education and Research. All rights reserved.

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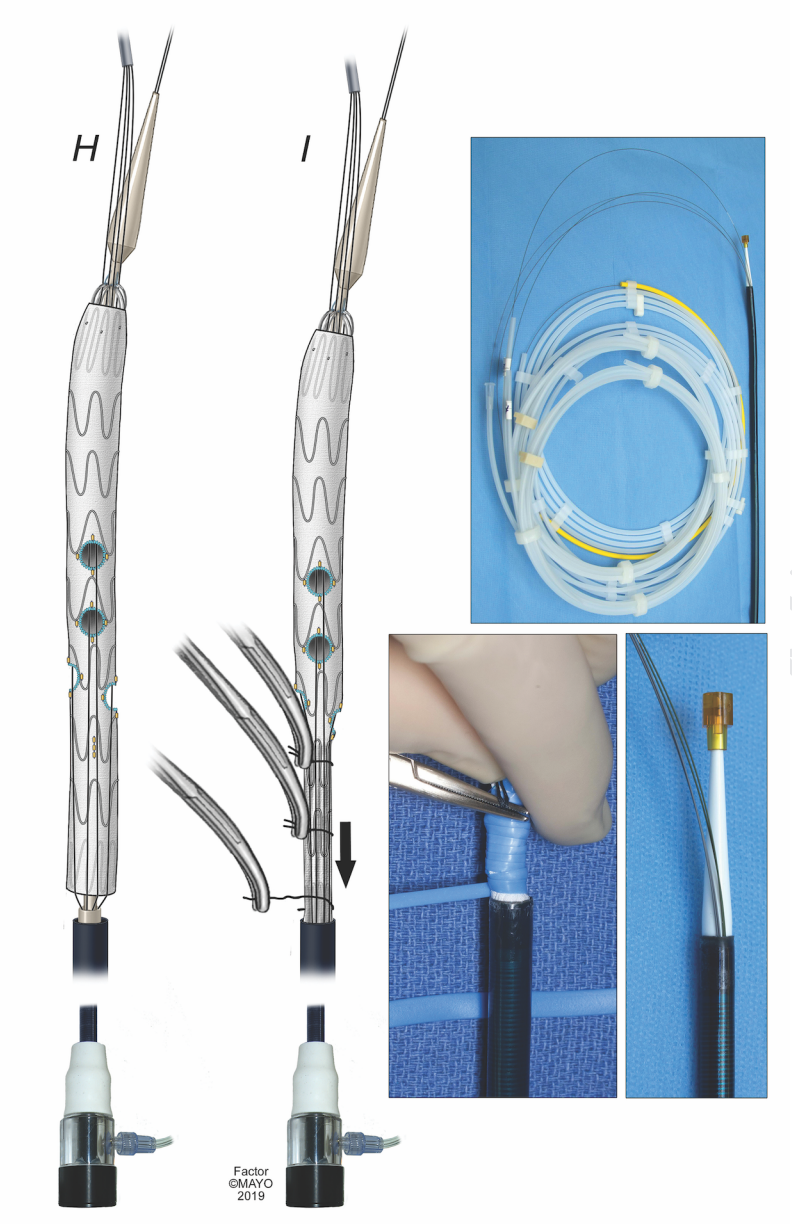
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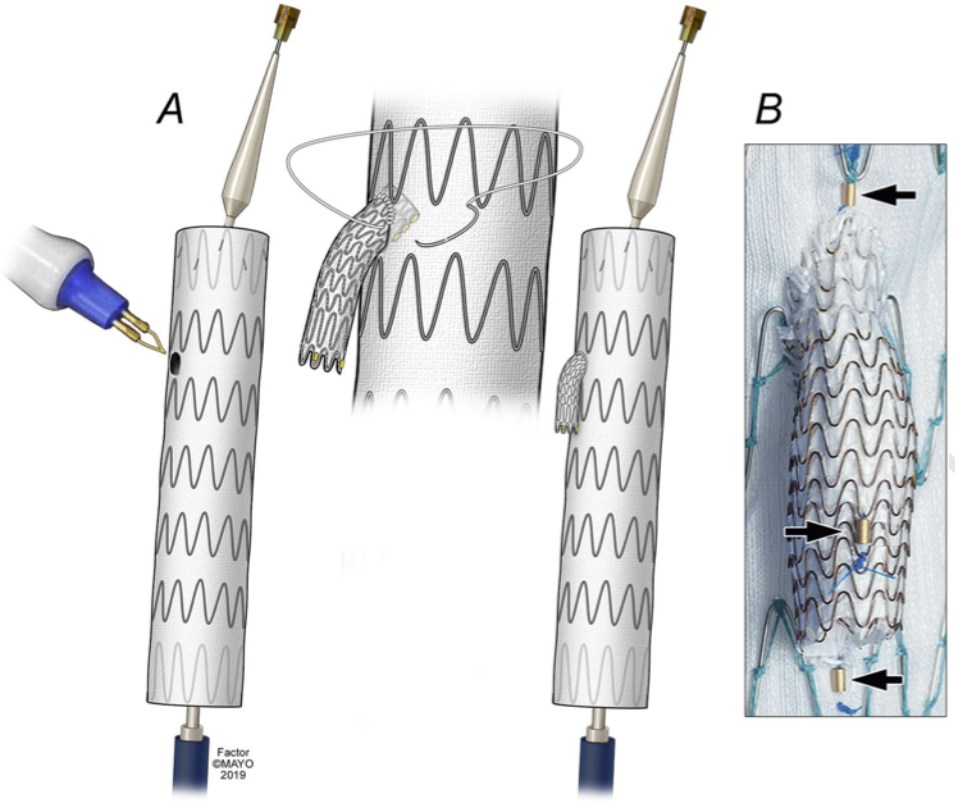

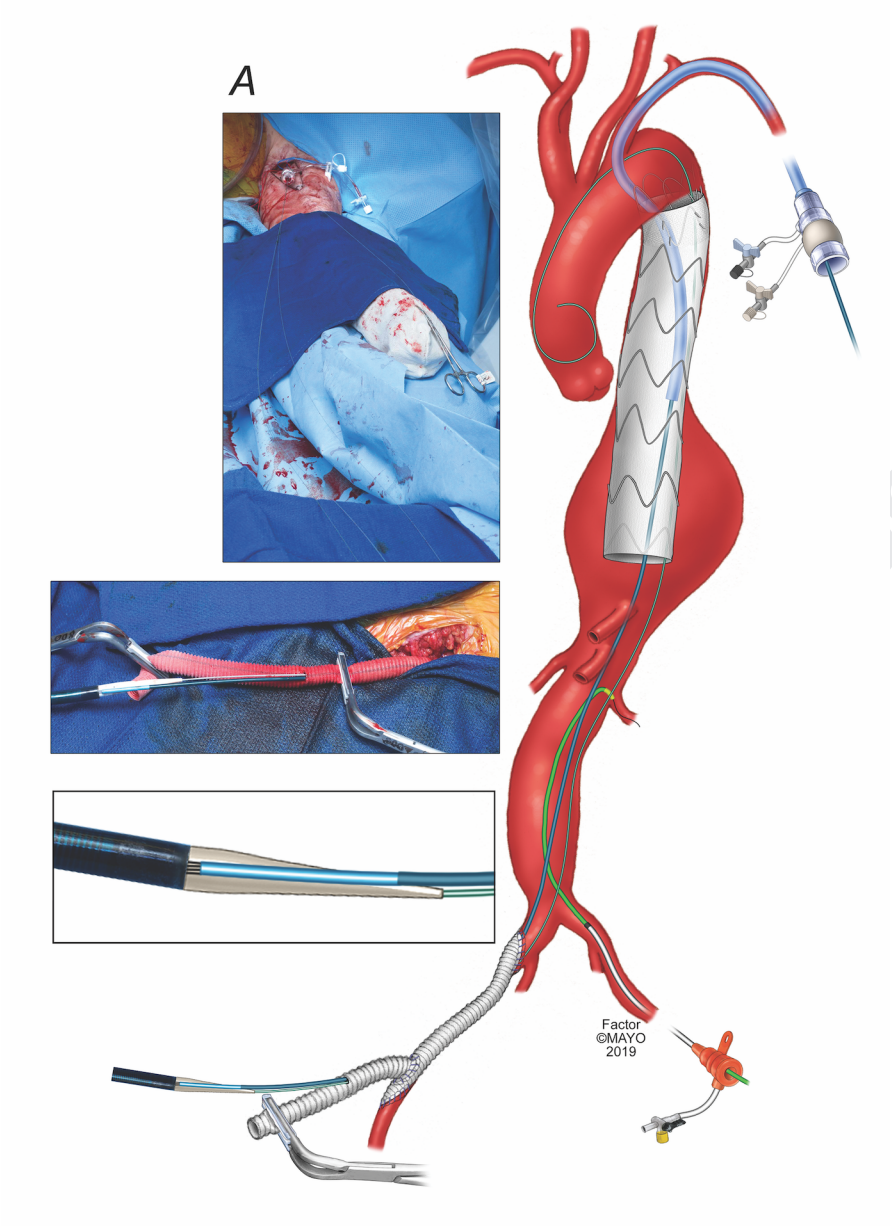
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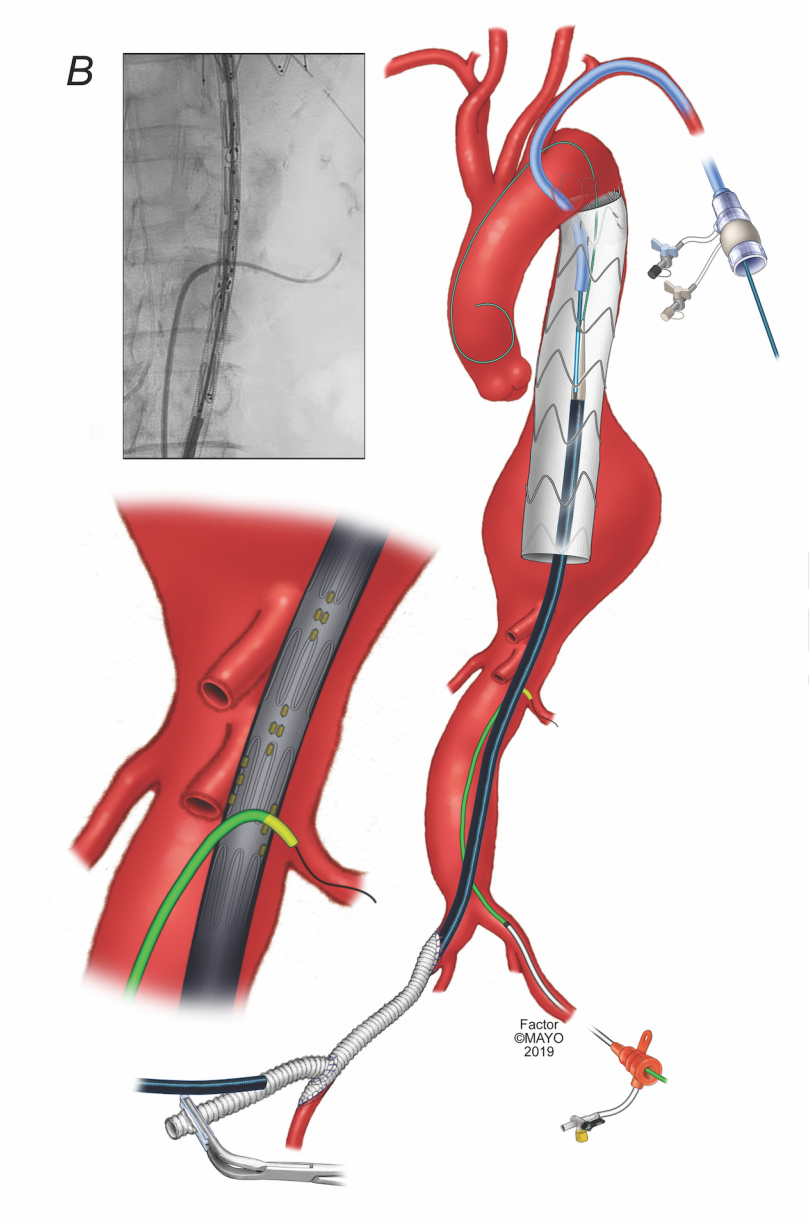
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